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Procedia - Social and Behavioral Sciences 195 (2015) 2130 – 2134

Procedia
Social and Behavioral Sciences

World Conference on Technology, Innovation and Entrepreneurship

Effects of Ammonium Nitrate on Physico-mechanical Properties and Formaldehyde Contents of Particleboard

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Abstract

In this study, the effects of hardener type (ammonium chloride and ammonium nitrate) and board thickness on the physical (density, thickness swelling and water absorption), mechanical (modulus of rupture, modulus of elasticity, internal bond strength, screw withdrawal resistance and surface durability) and formaldehyde content of particleboard were investigated. Three types panels were produced using 11-9% urea-formaldehyde adhesive (core and surface, respectively), with 650 kg/m^3 target density, 150°C pressing temperature, 20-24 kg/cm^2 pressure, and 6 min of pressing time. The analyses revealed that use of ammonium nitrate for particleboard manufacturing resulted in improved water absorption and thickness swelling properties after 24 h of immersion in water. In addition, the using ammonium nitrate has no significant effect by Modulus of rupture (MOR) and modulus of elasticity (MOE). However, internal bond strength, screw withdrawal resistance and surface durability properties were positively affected by using ammonium nitrate. Formaldehyde content value was decreased by about 5%. The study demonstrated that the boards made of ammonium nitrate meet the requirements for general standard and building materials.

Peer-review under responsibility of Istanbul Univeriesty.

Keywords: Particleboard, Ammonium nitrate, Formaldehyde content, Physical and Mechanical properties,

1. Introduction

Wood based composites, such as particleboards (PB), medium density fiberboard (MDF), plywood and wood plastic composite (WPC), are wide products used in the buildings, construction industry, and many consumer products. Depending on the desired use of site properties (strength, strong, economy) is able to produce various composites using chip, strands, veneer and fiber (Rowell, 2005). Particleboard has become one of the most popular

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Peer-review under responsibility of Istanbul Univeriesty.
doi:10.1016/j.sbspro.2015.06.270

wood-based composite materials for decoration and making furniture. It has good thermal and sound absorption properties, processing performance and low density (Yang et al., 2014).

Urea formaldehyde resins have been incredibly used in the production of PB and other wood based panels. The use of urea formaldehyde resin as a prime adhesive by the forest products industry is due to water solubility, lack of color, low cost and ease of use under a wide diversity of curing conditions. On the other hand, it has high hydrolysis sensitivity and low water durability (Maminski et al., 2008). The hardener solution is added to catalyse the resin curing reaction and it is presented as a rate of solid hardener substance to solid resin basis. The hardeners are added as late as possible to avoid premature curing due to production line stoppages (Moslemi, 1974).

The formaldehyde content of wood composites because of their formaldehyde-based resin content are a handicap in mostly application (Candan and Akbulut, 2013). Formaldehyde content brought on different side effects, most common of which are irritation in the upper respiratory tract and combustion in the eyes (Kim and Kim, 2004). It is realized that formaldehyde has a cancer-causing impact on human healthy (National cancer institute, 2012). Therefore, the reduction of free formaldehyde contents from composite wood has become a very important issue.

The objective of this study was to evaluate the physical and mechanical properties including density (D), Thickness swelling (TS), water absorption (WA), modulus of rupture, modulus of elasticity (MOE), internal bond strength (IB), screw withdrawal resistance (SWR), surface durability (SD) and also formaldehyde content (FC) of PB manufactured by using ammonium nitrate as a hardener.

2. Materials and Methods

2.1 Manufacturing of Experimental Panels

The PB panels were manufactured at Kastamonu Integrated Wood Company in Balıkesir, Turkey. Wood particles used for particleboard manufacturing consist of 90% pine (Pinus sylvestris L.) and 10% beech (Fagus orientalis L.) particles. Particles were dried to approximately 1% moisture content prior to application of resin. Board mats with dimensions of 3660mm (L) × 2100mm (W) × 18 and 8 mm (T) were hot pressed for 6 minutes to achieve a target board density of 650 kg/m3. Commercial UF resin with 62% solid content were used at 11% and 9% adhesive levels based on the oven-dry weight for the outer and core layers of PB, respectively. Two types of hardeners were used: ammonium chloride (NH_4Cl; concentration %10) and ammonium nitrate (NH_4NO_3; concentration 20%). Pressing pressure and temperature were 20-24 kp/cm2 and 150°C, respectively. The boards were designed to consist of 40% particles at the face layers and 60% at the core layer. After pressing, the boards were stored in climate room for further 30 days at 25°C and 65% relative humidity (RH). The experimental design is shown in Table 1.

Table 1 The experimental schedule for PB panel manufactured

Panel type	Hardener type	Panel thickness (mm)
A18	Ammonium chloride	18
N18	Ammonium nitrate	18
N8	Ammonium nitrate	8

2.2 Determination of Physical and Mechanical Properties

Before the test, samples were conditioned in a room climatized at 25°C and 65% RH to reach equilibrium moisture content. D of the panels was evaluated according to EN 323. TS and WA of the panels after 24 h water immersion was evaluated according to EN 317. Twenty replicate samples with dimensions of 50 mm × 50 mm × board thickness from each type of PB were used for the physical properties.

MOE, MOR and IB strengths of the specimens were determined on an Imal Pal board property tester IB600 based on EN 310 and EN 319, respectively. A total ten samples with dimensions of 400 mm × 50 mm × board thickness were tested for each variety of PB for MOR and MOE strength. Ten replicate samples with dimensions 50 mm × 50 mm × board thickness from each variety of PB were used to determine the IB. To determine screw withdrawal resistance (SWR) perpendicular to the plane of the board, fifteen samples with dimensions of 75 × 75 × 10 mm from each type of panel were tested according to EN 320. SD of the panels was also evaluated using EN 311. Ten replicate samples, 50 mm × 50 mm × board thickness, from each type of PB were used for SD test.

2.3 *Determination of Formaldehyde Content*

The formaldehyde contents of PB panels were determined according to EN 120. The formaldehyde was extracted from test samples of 110 g total, in 25 mm × 25 mm × board thickness pieces by means of boiling toluene (600 ml) for 2 h then transferred into water. Approximately 1000 ml of distilled water is added to the system. The distance between the water surface and the siphon equipment should be 20-30 mm. Then, formaldehyde was determined by iodometric titration. The total time required to perform was about 4 h (2 repeated).

2.3 Statistical Analysis

One way analysis of variance, ANOVA, was conducted ($p<0,05$) to evaluate the effects of ammonium nitrate on physico-mechanical properties and formaldehyde contents of the panels with SPSS 13.0. Significant differences between the mean values of the PB types were defined using Duncan test.

3. Result and Discussion

3.1 Physical and Mechanical Properties

Table 2 displays the results of density (D), thickness swelling (TS) and water absorption (WA) tests. The D data ranged from 632.45 to 645.83 kg/m3. There was no difference between the D values of the panels. WA and TS values (24 h immersion) of PB samples ranged from 41.75 to 54.89 % and 7.53 to 12.93 %, respectively. According to EN 312-4(1996), maximum TS value for 24 h is 15%. Therefore, the panels met the thickness swelling requirement for general uses. Water resistance properties were not affected by using ammonium nitrate. However, the results show that board thickness had a significant effect on water absorption values.

Table 2 Mean values of physical properties of particleboards

Panel type	D (kg/m^3)	WA (%)	TS (%)
A18	632.45 ± 10.86	54.89 ± 7.34 (a)	12,93 ± 3.58 (a)
N18	645.79 ± 11.73	49.35 ± 5.11 (ab)	11,51 ± 2.06 (a)
N8	645.83 ± 10.67	41.75 ± 1.47 (c)	7,53 ± 1.97 (b)

Note: different letters in the parentheses (in same column) represent statistical differences at 95% confidence level. Numbers in the parenthesis are standard deviations

The average values of MOR, MOE, IB, SWR and SD of experimental panels are offered in Table 3. According to EN standard, 11.5, 13.0 and 1600 N/mm2 are the minimum requirements for MOR and MOE of particleboard panels for general uses and interior fitments such as furniture (EN 312-2, 1996; EN 312-3, 1996). The MOR and MOE values of all the panels were higher than the general-purpose requirements. For 18 mm panel thickness, the using ammonium nitrate has no significant effect on MOR and MOE values. With the reduction of the panel thickness, MOR and MOE are increased. The IB data ranged from 0.41 to 0.43 N/mm2. The minimal requirements of internal bond strength in the EN standard are 0.24 N/mm2 for general purpose (EN 312-2, 1996), 0.35 N/mm2 for interior fitmets (EN 312-3, 1996) and 0.50 N/mm2 for heavy-duty load bearing panels (EN 312-4, 1996). According to test results, all type panels met the required levels of IB for both general purpose and interior fitments. IB strength was increased the using ammonium nitrate as a hardener. Ashori and nourbakhsh (2008) reported similar strength properties with particleboard from Pine (Pinus sylvestris L.) wood particles. In another study, MOR values of the boards manufactured with ammonium chloride were defined between 0.360 and 0.438 N/mm2 (Kalaycıoglu and Nemli, 2006).

Table 3 Mean values of mechanical properties of particleboards

Panel type	MOR (N/mm2)	MOE (N/mm2)	IB (N/mm2)	SWR (N/mm2)	SD (N/mm2)
A18	13.23 ± 1,61 (a)	2453.03 ± 249.91 (a)	0.41 ± 0.06 (a)	635.67 ± 64.70 (a)	1.12 ± 0.18 (a)
N18	13.36±1,64 (a)	2439.99 ± 176.35 (a)	0.47 ± 0.07 (b)	718.00 ± 116.61 (b)	1.41 ± 0.10 (b)
N8	14.26±2,336 (b)	2615.76 ± 401.86 (b)	0.43 ± 0.03 (c)	605.42 ± 73.22 (c)	0.72 ± 0.09 (c)

Note: different letters in the parentheses (in same column) represent statistical differences at 95% confidence level. Numbers in the parenthesis are standard deviations

The SWR values of the particleboard ranged from 605.42 to 718.00 N/mm^2. SWR values of particleboard with ammonium nitrate were improved 18% as compared to control board (A18). SD data ranged from 0.72 to 1.41 N/mm^2. SD values of the particleboards with ammonium nitrate increased 9% compared to controls panel (A18). However, board thickness had a negative effect on SWR and SD values. Acidity may be an important factor in the increase in IB, SWR and SD values. The good adhesion between the particles and successful curing occur at pH 4–5 (Lynam, 1969). Decreasing pH of the particles to the admissible levels for good adhesion and effective curing of urea formaldehyde adhesive caused better strength properties (Akyuz et al., 2010).

3.2 Formaldehyde content

Fig. 1 shows the result of formaldehyde content values. The FC values of the particleboard ranged from 7.67 to 8.86 mg/100 g. According to EN 120, the formaldehyde content values are ≤8 mg/100 g o.d for E_1 grade and >8 ≤ 30 mg/100 g for E_2 grade. The FC level of the A18 and N18 panels was the E_2 grade. As well, N8 panel was under E_1 grade. The resulting equations showed that board thickness had a significant effect on FC measured by EN 120. Salem at al. (2011) reported the similar results that when increasing the PB thickness, the emitted formaldehyde concentration increased. Formaldehyde content values were decreased by using ammonium nitrate as a hardener. This may be explained by ammonium nitrate holds more free formaldehyde than ammonium chloride.

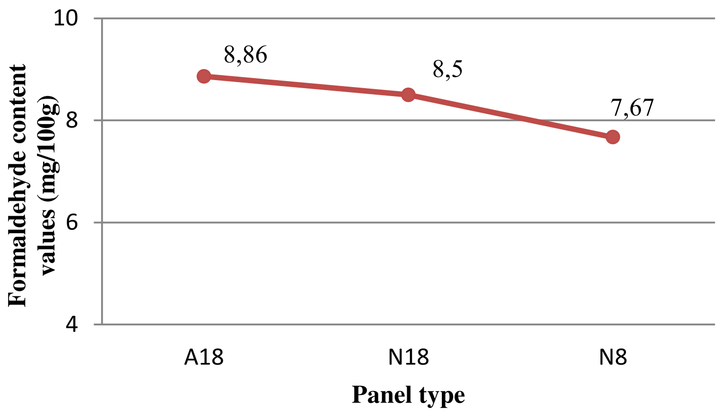

Figure 1 Average formaldehyde emission of the PB

4. Conclusions

This study evaluated the effect of ammonium nitrate on physico-mechanical properties and formaldehyde contents of PB panels. The results show that ammonium nitrate has no significant effect on D, MOR, MOE, TS and WA values. On the other hand, IB, SWR and SD were positively affected when FC was decreased. Besides, the reduction of the thickness reduced formaldehyde contents.

The above results suggest that it is completely feasible to manufacture acceptable and more environmentally friendly particleboard using ammonium nitrate as a hardener.

Acknowledgments

The authors acknowledge Kastamonu Integrated Wood Company in Balıkesir, Turkey which helps in making the production and performance test.

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